Final Report

Effectiveness of the Proposed Santa Fe City/County Water Treatment Plant for Removing Radiological and Other Specific Contaminants

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April 15, 2008

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Executive Summary

This report was prepared as an independent assessment of the ability of the City/County Water Treatment Plant (C/CWTP) to remove specific contaminants from Rio Grande water. The contaminants of interest are uranium, plutonium, americium, cesium, radium, strontium, tritium, perchlorate, chromium, polychlorinated biphenyls (PCBs), and pharmaceuticals, personal care products (PPCPs) and endocrine disruptors (EDCs). The report summarizes drinking water regulations, natural background and human exposure to radiation, concentrations measured in the Rio Grande, and the efficiency of treatment for each contaminant expected of the proposed C/CWTP process train.

The evidence indicates that the proposed C/CWTP will be able to reliably provide water to the community that meets all SDWA maximum contaminant levels on a continuous basis for all contaminants discussed in this report. This reliability results from a three-tiered barrier: (1) concentrations in the river that are nearly always below regulated levels, (2) an operational strategy that can prevent water possibly containing higher levels of contaminants from entering the plant, and (3) a robust treatment process that removes or could be modified to remove all the contaminants of interest.

Pertinent drinking water regulations are:

Maximum Contaminant Levels (MCLs) Established in the Safe Drinking Water Act.

Contaminant	MCL
Adjusted gross alpha activity (not including radon or uranium)	15 pCi/L
Beta particle and photon activity	4 mrem/yr
Radium-226/228 (combined)	5 pCi/L
Uranium	30 µg/L
Chromium	100 µg/L
Polychlorinated biphenyls	0.5 µg/L

Plutonium and americium are regulated as part of the MCL for adjusted gross alpha activity. Cesium, strontium, and tritium are included in the beta particle and photon activity regulation. Exposure to water containing radionuclides above the MCL continuously over long periods of time may cause cancer in some people. Perchlorate, PPCPs, and EDCs are not regulated but may be in the future. The United States Environmental Protection Agency has set a Drinking Water Equivalent Level guidance level of 24.5 µg/L for perchlorate.

Humans are exposed to natural radiation from a variety of sources, including cosmic radiation, terrestrial radiation, inhalation, and ingestion. Inhalation includes radon that accumulates in homes and other enclosed spaces and dust containing the decay products of naturally-occurring uranium and thorium that is present in all soils. Humans ingest food and water containing naturally-radioactive potassium, which is then incorporated into our physical composition and emits radiation from inside our bodies. Food and water also contain the decay products of naturally-occurring uranium and thorium. The total exposure to natural background radiation in northern New Mexico (Albuquerque area) has been estimated at 330 to 530 mrem/yr. In addition to these natural sources, humans expose themselves to various sources of manmade radiation. A 4-hour airline flight exposes a person to 2-3 mrem from increased cosmic radiation, a single chest x-ray can expose a person to 10 mrem, and a CT scan can expose a person to about 1000 mrem. The drinking water MCL for beta particle and photon activity at 4 mrem/yr and the radiation doses caused by exposure to alpha particle activity, radium, and uranium at their respective MCLs are relatively small compared to these other sources of radiation.

Samples of Rio Grande water and sediment have been collected and analyzed for the contaminants of interest. The results include hundreds of samples collected by several different agencies over several decades. Analytical results reported by Los Alamos National Laboratory (LANL) are consistent with results reported by the United States Geological Survey (USGS) and New Mexico Environment Department (NMED). The data record indicates that concentrations of plutonium, americium, tritium, chromium, perchlorate, and PCBs have always been below the applicable MCLs or target maximum concentrations. For the remaining contaminants, the long-term historical record indicates that activities are consistently 1 to 2 orders of magnitude below the target maximum concentration, but that a small number of excursions have occurred, including 2 samples for uranium, 1 sample for cesium-137, 2 samples for radium-226/228, and 3 samples for strontium-90. It is important to note that Safe Drinking Water Act (SDWA) regulations are based on the possibility of increased incidence of cancer when exposed to radionuclides in drinking water above the MCL continuously for long periods of time. Evidence of increased cancer risk from drinking treated Rio Grande water does not exist.

Regardless of the lack of evidence for increased cancer risk, it is imperative for the C/CWTP to continuously meet all regulations. In the event that an excursion causes concentrations in the Rio Grande to exceed target maximum concentrations, the design and operation of the C/CWTP must either (a) prevent the contaminated water from being delivered to the plant, or (b) remove the contaminants from the water. Both options are viable based on the design and operation of the proposed facility. The data record discussed previously also includes about 600 analyses for gross alpha and gross beta activity collected over a 50 year period. The alpha and beta data includes a small number of excursions above target levels. High alpha and beta activity correlates with high total suspended solids (TSS) concentrations, which occur when heavy rainfall washes sediments into the river. Thus, water containing high alpha and beta activity could be avoided by ceasing diversions when high sediment loads (measured as turbidity, a convenient continuous measurement) are detected in the source water. The activity of other radionuclides also seems to follow rainfall events. The highest activities of uranium, plutonium, americium, and radium were consistent with the high activities of alpha and beta during rainfall events. Two of the three strontium excursions occurred during rainfall events (no TSS data exists on the same days as the cesium excursion and the remaining strontium excursion, so no relationship can be inferred for those). Thus, an operational strategy that ceased diversions during high turbidity events would be protective against the distribution of water that possibly contained contaminants above the target levels.

The treatment plant includes processes that will effectively remove contaminants. A main component of the proposed plant is the coagulation/filtration process, which is designed to remove particles (such as sediment, clay, bacteria, viruses, colloids, etc) from water. The coagulation component of the process train preconditions small colloids so they can be removed by the filtration process even if they are smaller than the filter pore size. The selection of membrane filtration for this plant provides the highest available level of treatment for removing particles. Any contaminant bound to particles will be removed from the water when the particles are removed. Coagulation/filtration is listed as best available technology for uranium removal, and the discussion of chemical properties in the report demonstrates that plutonium and americium share similar chemical behavior with uranium. The CDM pilot plant, paired unfiltered/filtered samples from LANL, and scientific literature on the subject all indicate that the coagulation/filtration process in the plant will be able to remove these contaminants. Capabilities for removal of cesium, radium, and strontium are more dependent on the extent of adsorption to sediments. Scientific literature indicates that these contaminants sometimes but not always adsorb to sediments, depending on complex interactions between specific species in water and specific types of clay. Literature indicates that the conventional coagulation/filtration process does not remove these contaminants with high efficiency when they are not associated with particles. Nevertheless, the water quality data from the Rio Grande seems to suggest that these contaminants are associated with sediments on the few occasions when they (possibly) were detected above the target maximum concentrations, indicating that the proposed plant will be able to remove them.

Furthermore, scientific literature suggests that modifications to the conventional coagulation/filtration process, such as the addition of specific types of clay, adjustment of pH, or addition of barium to co-precipitate radium, may be possible. Coagulation/filtration is also listed as a best available technology for removing chromium, and the plant contains granular activated carbon adsorption, which is listed as a best available technology (BAT) for PCBs. These latter two contaminants, however, were never observed above the maximum target concentrations in the source water.

If it is determined that additional cesium, radium, or strontium removal is desired, or if a process were needed to remove perchlorate, the ion exchange or reverse osmosis process would be effective for all of these contaminants. Reverse osmosis would be the less practical of the two because of the challenges associated with waste production and high energy consumption. While it would be possible to add either of these processes to the plant in the future, inclusion in the process train at this time does not seem warranted based on the concentrations observed in the river, the ability to cease diversions during rainfall events, and the likely ability of the proposed process train to remove these contaminants.

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Abbreviations

Am	americium
ANS	American Nuclear Society
BDD	Buckman Direct Diversion
C/CWTP	City/County Water Treatment Plant
CCL	contaminant candidate list
CDM	Camp Dresser & McKee, Inc
Cs	cesium
DWEL	Drinking Water Equivalent Level
EDCs	endocrine disruptors
EPA	United States Environmental Protection Agency
GAC	granular activated carbon
HTO	tritiated water
K	potassium
LANL	Los Alamos National Laboratory
MCL	maximum contaminant level
mrem/yr	millirem/year
NMED	New Mexico Environment Department
PCBs	polychlorinated biphenyls
pCi/L	picocuries/liter
PPCPs	pharmaceuticals and personal care products
Pu	plutonium
Ra	radium
rem	Röntgen equivalent man
RO	reverse osmosis
SI	le Système International d'Unités
SDWA	Safe Drinking water Act
Sr	strontium
Th	thorium
TSS	total suspended solids
U	uranium
USGS	United States Geological Survey
µg/L	micrograms/liter

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Removing Radiological and Other Specific Contaminants

1. Introduction

This report was prepared for the City of Santa Fe and the Buckman Direct Diversion (BDD) Board as an independent assessment of the effectiveness of the proposed City/County Water Treatment Plant (C/CWTP) for removing contaminants from water withdrawn from the Rio Grande. Specific contaminants are of interest because of the proximity of the proposed intake to the Los Alamos National Laboratory (LANL) and the perceived potential for radioactive contaminants or other materials to be present in the treatment plant's source water. The specific contaminants addressed in this report are:

Uranium
Plutonium
Americium
Cesium
Radium
Strontium
Tritium
Perchlorate
Chromium
Polychlorinated biphenyls (PCBs)
Pharmaceutical and personal care products (PPCPs) and endocrine disruptors (EDCs)

This report is divided into eight sections including this introduction. After the introduction, the second section presents general background material on radioactivity and the units that are used to measure contaminants—radioactive and otherwise—in regulations and water quality samples. Next, water quality regulations as specified in the federal Safe Drinking Water Act are presented. The regulatory section provides the context for the measured concentrations and the objectives for treatment. The next section presents data on natural background radiation and the amount of radiation that humans are exposed to from a variety of common activities. The fifth section summarizes available data about the concentrations and activities of the contaminants of interest in the Rio Grande water and sediments. The sixth section identifies the impact that the Los Alamos Canyon has on the water and sediment flow in the Rio Grande. The seventh section presents information on the chemistry of each contaminant and the speciation that would exist in conditions representative of the Rio Grande. This section is important because the chemistry and speciation of each contaminant affects the efficacy with which various treatment processes are able to remove each contaminant. The last section describes the basic function of each process in the C/CWTP and the ability of the plant to remove the contaminants of interest.

2. Radioactivity

Three types of nuclear radiation are relevant to this report—alpha, beta, and gamma radiation. The basic properties and effects of these types of radiation are presented in this section to provide some background and context. Following a short discussion of these types of radiation, the units of radioactivity used for regulatory purposes are presented.

Alpha Particles

An alpha particle consists of two protons and two neutrons, and is therefore equivalent to a helium nucleus. Relative to other types of ionizing radiation, the alpha particle is heavy, high-energy, and slow moving. The loss of an alpha particle from an atom changes the atom into a new element with an atomic number 2 lower than the original atom; for instance, plutonium (atomic number 94) transmutes into uranium (atomic number 92).

Other than the nuclear power industry, some common uses of alpha-emitting elements are the use of radium-226 for treating cancer and the use of americium-241 in common household smoke detectors.

Because of their large mass, alpha particles lose energy rapidly and do not travel far. They travel only a few inches in air and cannot penetrate common objects, including paper or skin. They lose energy as they travel through air, and once they have lost their energy they pick up electrons and become helium. Since alpha particles cannot penetrate the outer, dead layers of skin, external exposure to alpha-emitting elements is not a significant health issue. However, if alpha-emitters are transported inside the body by inhalation into the lungs or ingestion through food or drinking water, the potential for health effects are greater. Within the body, exposure to alpha particles over long periods can cause cancer.

Beta Particles

Beta particles are subatomic particles that have a charge of -1 and a mass of 5.49×10^{-4} Daltons. In essence, they are high-energy, high-speed electrons that are ejected from the nucleus of an atom. During beta decay, a neutron is converted to a proton. The loss of a beta particle from an atom changes the atom into a new element with an atomic number 1 higher than the original atom; for instance, strontium (atomic number 38) transmutes into yttrium (atomic number 39).

Beta emitters occur naturally and are used for a variety of human purposes. Tritium has been used in luminous dials on watches and other objects and Carbon-14 is the basis for determining the age of organic materials.

Beta particles will travel several feet in air before losing their energy. Once they lose their energy, they act like any other free electron and are picked up by positive ions. They are readily stopped by solid objects. Within the body, exposure to beta particles over long periods can cause cancer.

Gamma Rays

Gamma rays have no charge or mass. They are high-energy photons with energy about 10,000 times the energy of visible light photons. Their emission releases energy from the nucleus of an atom, which helps make it more stable but does not change the number of protons or neutrons. Gamma rays often accompany the emission of beta particles. Gamma rays travel at the speed of light and exist only as long as they have energy. Once their energy is spent, whether in air or in solid materials, they cease to exist. The same is true for x-rays. Because of their high energy, gamma rays can travel great distances through air and through most solid objects. Lead or other dense materials are used for shielding to stop gamma radiation.

Gamma radiation is used for many purposes. The three most commonly used gamma emitters are cobalt-60 (used for cancer treatment, sterilization, pasteurization, thickness measurement, and inspection of welds and parts), cesium-137 (used for cancer treatment, flow and density measurement), and technetium-99 (used for medical diagnostics).

Gamma rays and x-rays pose the same hazard to humans. The primary differences between gamma rays and x-rays are that gamma rays originate in the nucleus and X-rays originate in the electron fields surrounding the nucleus, and gamma rays have somewhat more energy.

Units of Radioactive Decay (pCi/L)

For health effects caused by radionuclides, the rate of emission, or decay rate, is more important than the concentration. The SI unit of radioactive decay is the Becquerel, which is one decay per second. US Environmental Protection Agency (EPA) regulations use a common non-SI unit, the curie, which is equal to 3.7×10^{10} decays/second. EPA regulates the decay rate per volume of water (i.e., activity) in picocuries/liter, abbreviated pCi/L. One pCi/L corresponds to a quart of water containing enough radioactive material to produce a single radioactive decay about every 30 seconds.

Units of Equivalent Dose (mrem/yr)

Beta and gamma radiation can be produced by 126 different isotopes. Each causes different amounts of biological damage, so a regulation based solely on the decay rate is not sufficient to determine harm to humans. The important parameter is the product of the adsorbed dose of radiation and the biological efficiency. The SI unit of equivalent dose is the Sievert. EPA uses a common non-SI unit, the Röntgen equivalent man, or rem (100 rem = 1 Sievert). EPA regulates beta and gamma emitters in units of millirem/year, abbreviated mrem/yr. A look-up table specified in the regulations is used to determine the allowed activity for each isotope with respect to the 4 mrem/yr limit. When multiple isotopes are present, the contribution of each to the total 4 mrem/yr limit must be calculated on a weighted basis.

Units of Concentration (μg/L)

Most contaminants in drinking water are regulated based on the concentration (i.e., mass per volume) in water, since humans drinking a certain volume of water would be exposed to a higher mass of contaminant if the water contained a higher concentration. Uranium is regulated in μg/L, as are most non-radiological contaminants.

3. Water Treatment Regulations

Regulations for radionuclides in drinking water were first passed in 1976 and updated in 2000. The 2000 Radionuclides Rule [1] reaffirmed the maximum contaminant levels (MCLs) for alpha activity, beta activity, and radium, but added a new MCL for uranium. The current regulations are shown in Table 1.

Table 1. Maximum Contaminant Levels Established in the Radionuclides Rule [1].

Contaminant	MCL	Year
Adjusted gross alpha activity (not including radon or uranium)	15 pCi/L	1976
Beta particle and photon activity	4 mrem/yr	1976
Radium-226/228 (combined)	5 pCi/L	1976
Uranium	30 μg/L	2000

The possible health effects for alpha, beta, photon, and radium is that some people who drink water in excess of the MCL over many years may have an increased risk of getting cancer. For uranium, the health effects may include kidney toxicity in addition to the increased risk of cancer caused by uranium being an alpha emitter.

Some of the radionuclides being addressed in the report are not listed individually in the Radionuclides Rule. All, however, are either alpha emitters or beta emitters and are therefore included within the applicable MCL. In other words, all of the radionuclides discussed in this report are regulated under either the adjusted gross alpha activity MCL or the beta particle and photon activity MCL. The mode of radioactive decay of each isotope of each radionuclide considered in this report, along with the half-life, is shown in Table 2.

The non-radiological contaminants addressed in this report are perchlorate, chromium, PCBs, and PPCPs. MCLs exist in current Federal and state regulations for chromium and PCBs. No regulations exist for most pharmaceutical and personal care products in drinking water.

Table 2. Decay Mode and Half-life of Relevant Isotopes.

Isotope	Decay mode	Half life [2]
Tritium	beta	12 years
Strontium-89	beta	50 days
Strontium-90	beta	29 years
Cesium-137	beta	30 years
Radium-226	alpha	1,600 years
Radium-228	beta	5.8 years
Uranium-234	alpha	250,000 years
Uranium-235	alpha	7.0×10^8 years
Uranium-238	alpha	4.5×10^9 years
Plutonium-238	alpha	88 years
Plutonium-239	alpha	24,000 years
Plutonium-240	alpha	6,600 years
Americium-241	alpha	430 years

An MCL does not exist for perchlorate, but it is included on the contaminant candidate list [3] (CCL), which means that EPA may regulate it in the future. EPA has issued guidance setting a Drinking Water Equivalent Level (DWEL) of 24.5 μg/L [4]. This concentration is the level believed to have no adverse effect with a margin of safety, based on a National Academy of Science study. California has set an MCL of 6 μg/L [5], so this value will be used for reference in this report.

The target maximum concentration for each contaminant is summarized in Table 3. As shown in Table 3, plutonium and americium are included under the gross alpha activity MCL and cesium, strontium, and tritium are included under the beta MCL. The target maximum activities shown for cesium, strontium, and tritium are the activities that correspond to a 4 mrem/yr equivalent dose and are taken from the lookup table specified in the Radionuclides Rule.

Table 3. Target maximum concentration of each contaminant.

Contaminant	Target maximum concentration
Adjusted gross alpha activity	15 pCi/L
Plutonium-238	
Plutonium-239/240	
Americium-241	
Beta and photon radioactivity (4 mrem/yr)	
Cesium-137	200 pCi/L
Strontium-90	8 pCi/L
Tritium	20,000 pCi/L
Combined radium-226/-228	5 pCi/L
Uranium	30 μg/L
Chromium (total)	100 μg/L
PCBs	0.5 μg/L
Perchlorate	6 μg/L

4. Background Radiation and Contamination

Humans are exposed to radiation from a variety of natural and manmade sources. Natural sources include cosmic rays and naturally occurring radioactive isotopes in soil, air, food, and water that are inhaled or ingested as part of normal everyday activities. Exposure to manmade sources of radiation occurs from everyday objects such as smoke detectors, pollution from industrial processes such as coal-fired power plants, and fallout from global atmospheric nuclear testing in the 1940s to 1960s. The worldwide average human exposure to background radiation from natural sources is estimated to be 240 mrem/yr [6]. The primary natural sources include:

cosmic rays – 40 mrem/yr
terrestrial gamma rays – 50 mrem/yr
inhalation (mostly radon) – 120 mrem/yr
ingestion – 30 mrem/yr

Cosmic radiation is affected by both latitude and altitude, with higher latitude and altitude both contributing to increases in the exposure. Aircraft passengers are exposed to additional cosmic radiation ranging from about 0.5 to 0.8 mrem/hr, so that a 4-hour airline flight exposes a passenger to a radiation dose of 2 to 3 mrem.

Terrestrial exposure results from trace levels of naturally occurring radionuclides that are present in all soils. The primary sources are potassium (K-40) and the decay series of U-238 and Th-232. Research has shown that radiation exposure is greater indoors than outdoors because humans are surrounded by radioactive material rather than being exposed from one direction.

Nearly all of the radiation exposure from inhalation is from radon. Radon is the gaseous radioactive decay product of naturally occurring radium and accumulates in indoor spaces. Additional minor sources of radiation from inhalation include dust that contains naturally occurring isotopes. The effective dose from the uranium and thorium decay series (by inhalation of dust) adds 5.8 mrem/yr on top of the dose from radon.

Radiation from ingestion comes from both food and water. The primary sources of radiation in food and water are potassium (K-40) and the decay series of U-238 and Th-232. Potassium is common in most meats, fruits, and vegetables, but some foods like bananas are particularly high in potassium. Potassium is an essential nutrient and is incorporated into the body after being consumed. The estimated radiation dose from K-40 present in the human body is 16.5 mrem/yr for adults and 18.5 mrem/yr for children. The effective dose of radiation from the uranium and thorium decay series from ingestion is 11 mrem/yr.

The worldwide average exposure to manmade radiation is about 40 mrem/yr, although individual exposure varies widely. The most significant source of manmade radiation is medical procedures. A single dose from diagnostic medical procedures ranges from 10 mrem for a chest x-ray to about 1000 mrem for an abdominal CT scan [7]. The radiation exposure from fallout from atmospheric nuclear testing is 0.5 mrem/yr [6]. A summary of typical human exposures to radiation from natural and manmade sources is presented in Figure 1.

Individual background doses vary widely; about 10 percent of the world population receives natural background radiation doses above 300 mrem/yr. Exposure to background radiation in New Mexico is higher than worldwide averages. Brookins [8] estimated the exposure to background radiation in Albuquerque, NM to be 330 to 530 mrem/yr, well above the worldwide average. The higher radiation exposure was attributed to the altitude at 5200 ft (which increased cosmic radiation), higher than average natural concentrations of potassium, uranium, and thorium in the soil, and higher than average exposure to radon gas. The American Nuclear Society and the Environmental Protection Agency have on-line calculators to allow individuals to calculate their personal radiation dose. The websites are available at:

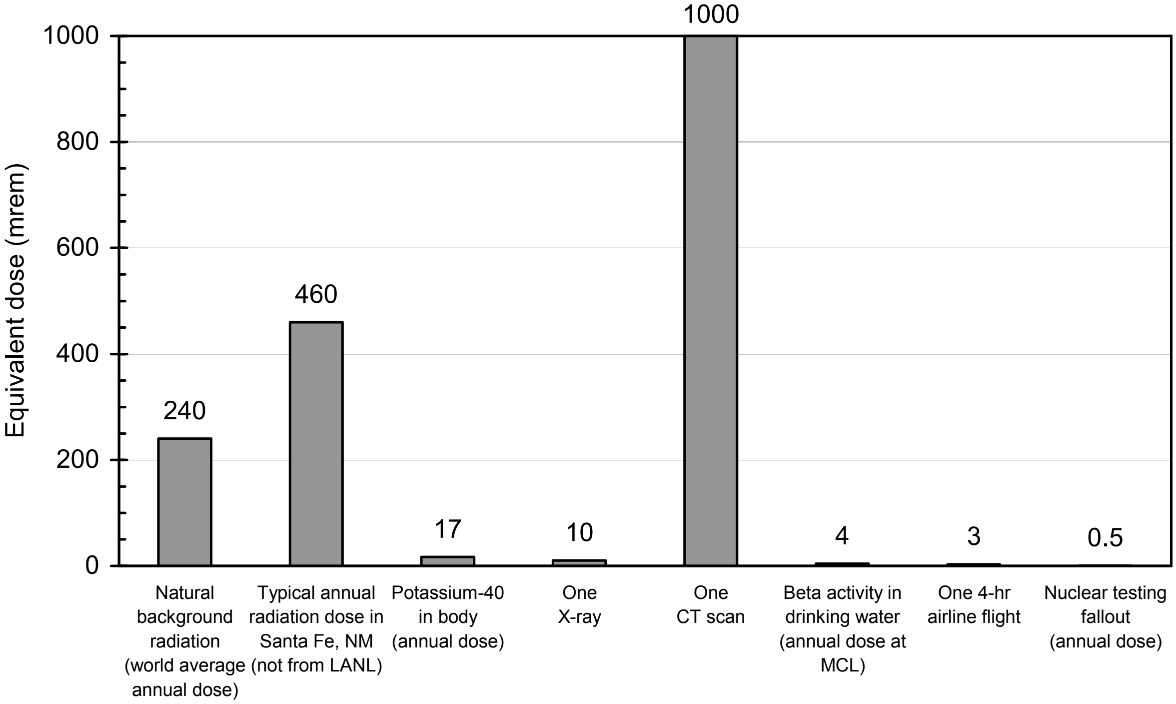

Figure 1 – Comparison of Typical Human Radiation Exposure From Natural and Manmade Sources

ANS: http://www.ans.org/pi/resources/dosechart/
EPA: http://www.epa.gov/rpdweb00/understand/calculate.html

The calculated annual dose from the EPA website for someone living at an elevation of 7000 to 8000 feet in the Colorado Plateau region (representative of Santa Fe), receiving one x-ray and travelling 5,000 miles by aircraft per year is about 460 mrem/yr; this value is shown in Figure 1 for comparison purposes.

Uranium is naturally present in the environment. Natural uranium in the earth has an average composition of 0.0057 percent U-234, 0.719 percent U-235, and 99.275 percent U-238 [9]. The average abundance of uranium in the Earth's crust is reported to be 2.7 µg/g and the average concentration in seawater is 3.3 µg/L [9]. Uranium tends to be more prevalent in minerals containing higher silica content. Literature reports that uranium concentrations tend to be higher in New Mexico, which explains the presence of uranium mines in the state.

5. Contaminant Concentrations in the Rio Grande

Water quality data for the identified contaminants were obtained from a number of sources, including LANL [10], the United States Geological Survey (USGS) [11], CDM [12], and Graf [13]. The LANL data represents 7 locations (Bernalillo, Embudo, Frijoles, Otowi, Ancho, Cochiti, and White Rock) over a 50 year period of record. The record includes sampling locations that are both upstream and downstream of the proposed BDD intake site and the confluence of Pajarito

Plateau canyons that drain LANL property. Although the USGS maintains several sampling locations along the Rio Grande, the data in this report is specifically for the Otowi site, the nearest USGS sampling station upstream from the proposed BDD intake and upstream of the confluence of Pajarito Plateau canyons that drain LANL property. The CDM data was taken at the location of the planned BDD diversion site, which is downstream from the Los Alamos and Pueblo Canyons confluence with the Rio Grande. In addition, suspended and bed sediment data were obtained from USGS and the New Mexico Environment Department (NMED) [14]. The NMED sediment data was collected at 5 locations (Santa Clara, Cañada Ancha, Pajarito, Water Canyon, and Frijoles). Of these, Santa Clara is upstream of any effects of LANL, Cañada Ancha is the location of the proposed BDD intake, and the remaining 3 locations are downstream of the proposed intake. Summaries of this data are shown in Tables 4 through 7. The results of this assessment are described in this section, tabulated by parameter.

Gross Alpha Activity

The gross alpha activity in the water column was measured by LANL, USGS, and CDM. The LANL water quality database contains results for 220 analyses of alpha activity in Rio Grande water, spanning a period of 5 decades between 01 Jan 1956 and 26 Sept 2007. The USGS reported 8 samples of filtered water and an additional 11 samples of suspended sediment. CDM collected 9 river water samples, 3 during rain events and 6 during non-rain events.

As noted earlier, the MCL for gross alpha activity is 15 pCi/L (although the EPA standard excludes the activity from uranium and radon). In the LANL data set, 11 samples were above this level (one of which was a duplicate). Three of these were taken at different locations (Embudo, Otowi, and Cochiti) on the first day of the data record, 01 Jan 1956. No gross alpha activity results exist between 1956 and 1967, but multiple samples were taken nearly every year from 1967 to 1982 and from 1992 to 1997 with no samples above 15 pCi/L. On 05 Aug 1998 at Otowi, 30 Sept 1998 at Frijoles, and 03 Aug 1999 at Otowi the gross alpha activity was 15.5, 21.6, and 19.2 pCi/L, respectively.

The highest gross alpha activity in the Rio Grande in the LANL data set occurred during 2 storm events in 2003. On 25 Aug 2003, the alpha activity was recorded as 235 pCi/L at Otowi and 20.5 pCi/L at Ancho. On 06 Sept 2003, the alpha activity was recorded as 46 pCi/L at Otowi and 45.7 pCi/L at White Rock. The impact of rain is demonstrated by high suspended sediment load in the river; the total suspended solids (TSS) concentrations at Otowi were 9850 mg/L on 25 Aug 2003 and 4710 mg/L on 06 Sept 2003.

The USGS data record for Otowi exists between the years 1979 and 1985. More data is not available because the USGS modified their analytical methods several times, and data in other periods is not reported in comparable units. The USGS reports gross alpha activity for both filtered samples and suspended sediment. No samples contained gross alpha activity above 15 pCi/L.

Gross alpha particle activity was detected in all 9 samples of raw river water collected during the CDM pilot study, with results ranging from 3.31 to 227 pCi/L. The highest measured activities occurred during storm events, and the measured activity on days without reported rain was typically below 15 pCi/L. On 7 of the sampling episodes, a paired sample was collected from

Table 4 – Concentration of Contaminants in Rio Grande Water Summarized From the LANL Water Quality Database (Multiple Locations).

	Alpha	Am-241	Pu-239/240	U-234	U-235/236	U-238
Date range	1956-2007	1975-2007	1961-2007	2000-2007	2000-2007	2000-2007
Number of samples	220	81	354	43	43	43
Number above 15 pCi/L	11	0	0	2	0	2
Median, pCi/L	1.6	0.014	0.005	1	0.091	0.62
Mean, pCi/L	4.7	0.015	0.19	6.2	0.76	6
Maximum, pCi/L	235	0.12	2.76	108	9.55	111

	Beta	Cs-131	Sr-90	Tritium
Date range	1956-2007	1973-2007	1976-2007	1967-2005
Number of samples	253	231	87	262
Number above 50 pCi/L	11	35	0	125
Median, pCi/L	5.9	4	0.45	300
Mean, pCi/L	20.9	26	0.87	648
Maximum, pCi/L	1110	1200	13.3	6500

Table 5 – Concentration of Contaminants in the Sediments at Cañada Ancha (NMED)

Contaminant	Background activity (from LANL report) (pCi/g)	Maximum found in Canada Ancha sediments (pCi/g)	Concentration in water assuming 10,000 mg/L TSS (pCi/L)
Pu-238	0.0087	0.0056	0.056
Pu-239/240	0.013	0.067	0.67
Am-241	0.076	0.026	0.26
Sr-90	1.02	0.64	6.4
Cs-137	0.56	0.98	9.8
Uranium	4.49 ug/g	5.98 ug/g	59.8 ug/g

Table 6 – Concentration of Contaminants Measured During the CDM Pilot Study.

	Alpha		Beta		Ra-226/228	
	raw	treated	raw	treated	raw	treated
Date	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
5/18/2005	10.3	<3	17.6	<4	<2	<2
6/1/2005	3.91	<3	6.03	<4	<2	<2
7/18/2005	10.3	<3	28.5	2.84	<2.24	<2
8/12/2005 (rain)	117	0.506	200	4.4	5.918	<2
8/16/2005	3.31	<3	5.58	3.14	<2	<2
9/14/2005	3.51	<0.05	5.85	4.02	0.442	0.585
9/28/2005 (rain)	227		319		11.7	
10/11/2005 (rain)	7.99		12		2.36	
10/25/2005	49.98	39.45	99.2	97.8	<1.46	<1.08

	Uranium		Chromium		PCBs	
	raw	treated	raw	treated	raw	treated
Date	ug/L	ug/L	mg/L	mg/L	ug/L	ug/L
5/18/2005	2.22	<0.2	0.005	0.002	<0.1	<0.1
6/1/2005	1.11	<0.2	0.003	0.002	<0.1	<0.1
7/18/2005	3.19	0.103	0.007	<0.001	<0.1	<0.1
8/12/2005 (rain)	14.5	1.38	0.014	0.004	<0.1	<0.1
8/16/2005	2.64	0.272	0.007	0.005	<0.1	<0.1
9/14/2005	2.11	<1	0.00278	0.00111	NM	NM
9/28/2005 (rain)	8		0.009		<0.1	
10/11/2005 (rain)	5		0.004		<0.1	
10/25/2005	3.4	2.2	NM	0.006	<0.1	<0.1

	Am-241		Pu-238		Pu-239/240		Cs-137	
	raw	treated	raw	treated	raw	treated	raw	treated
	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
8/2/2005	<0.424		<0.696		<0.483		<3.04	
8/12/2005 (rain)	<0.771	<0.385	<0.581	<0.605	<0.662	<0.689	<4.62	<4.73
9/28/2005 (rain)	<0.586		<0.184		<0.403		<3.47	
10/25/2005		<0.0256		<0.0002		0.0002		<6.67

	Sr-89		Sr-90		Tritium		Perchlorate	
	raw	treated	raw	treated	raw	treated	raw	treated
	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	ug/L	ug/L
8/2/2005	<1.14		<4.20		21.3		0.05	
8/12/2005 (rain)	24.7	<9.7	<5.71	<3.5	20.9		0.12	
9/28/2005 (rain)	<0.713		39.7		21.5		0.097	
10/25/2005				<0.445		19.4		0.08

Table 7 – Concentration of Contaminants in Rio Grande Water at Otowi Summarized From the USGS Water Quality Database.

	Alpha[1] filtered pCi/L	Alpha[1] suspended pCi/L	Beta[2] filtered pCi/L	Beta[2] suspended sediment pCi/L	Ra-226 filtered pCi/L	Uranium filtered ug/L
Date range	1979-1984	1979-1985	1974-2001	1974-1993	1974-2003	1974-2007
Number of samples	8	11	42	38	80	136
Number above detection limit	7	11	40	37	77	134
Minimum	2.7	0.3	1.4	0.8	0.007	<1
Median	3.7	2.3	4.3	3.6	0.06	2.2
Mean	3.87	3.56	4.22	9.76	0.088	2.34
Maximum	5.4	12	7	200	0.67	6.1

1. Alpha activity is based on a calibration curve using natural uranium
2. Beta activity is based on a calibration curve using Cs-137

	Sr-90		U-234			U-235			U-238			Cs-137	Tritium
Date	unfiltered pCi/L	filtered pCi/L	unfiltered pCi/L	filtered pCi/L	bed sediment pCi/g	unfiltered pCi/L	filtered pCi/L	bed sediment pCi/g	unfiltered pCi/L	filtered pCi/L	bed sediment pCi/g	bed sediment pCi/g	unfiltered pCi/L
7/6/2000	<0.5	<0.5	0.6	0.5	<1	<0.1	<0.1	M	0.4	0.3	<1	0.13	53
7/27/2001	2.2	0.3	3.1	0.6	0.2	0.1	M	M	2.8	0.4	0.2	0.06	28
8/9/2001	0.2	0.2	1.2		0.2	M		M	0.8		0.3	0.08	26
9/26/2001	0.2	0.1	0.8	0.8	0.2	M	M	M	0.5	0.5	0.2	0.05	22

the effluent of the pilot treatment plant. Five of the treated water samples were below the detection limit. The sixth was 0.506 pCi/L. This sixth sample corresponded to the storm event with 117 pCi/L of alpha activity in the raw water, so the treated water activity represents a removal efficiency of 99.5 percent. The last paired sample was above 15 pCi/L, but apparently was taken during a time when the pilot plant was not operating correctly, including restarting of the filters and erratic flow through the filters [15].

Evidence that filtration can remove gross alpha particle activity was also present in the LANL data record. During 7 sampling episodes, both filtered and unfiltered samples were collected and analyzed by LANL. On 3 of those occasions, the filtered sample was below the detection limit. The overall trend was that the higher the activity in the unfiltered sample, the higher removal efficiency was achieved, with 95 percent removal efficiency occurring in the samples at Otowi and White Rock on 06 Sept 2003. It should be noted that a laboratory filter for determining filtered and unfiltered constituent concentrations is not as efficient as the process in the proposed BDD water treatment plant.

In summary, in over 250 samples collected over a 50-year period by 3 different organizations at locations both upstream and downstream of LANL influences, only a handful of samples contained gross alpha particle activity above the MCL of 15 pCi/L. The highest activity measurements occurred during storm events. In addition, the data record contains sufficient evidence that filtration can be effective at removing gross alpha particle activity in Rio Grande water to well below the 15 pCi/L limit, with removal efficiency up to 95 percent.

Beta and Photon Activity

The beta activity in the water column was measured by LANL, USGS, and CDM. The LANL water quality database contains results for 253 analyses of beta activity in Rio Grande water, spanning a period of 5 decades. The USGS reported 42 samples of filtered water and an additional 38 samples of suspended sediment. CDM collected 9 river water samples, 3 during rain events and 6 during non-rain events.

As noted earlier, the MCL for beta and photon activity is 4 mrem/yr. For vulnerable systems, EPA requires quarterly sampling for beta activity. If the gross beta activity minus the naturally occurring potassium-40 activity is greater than 50 pCi/L, the system must speciate to determine the specific source of the beta activity. Thus, 50 pCi/L serves as a relevant trigger level. In the LANL data set, 11 samples were above that value (one of which was a duplicate). Six of those were prior to 1970. The only gross beta activity above the 50 pCi/L level since 2000 was during the same 2 storm events that had high alpha activity levels. On 25 Aug 2003, the beta activity was recorded as 298 pCi/L at Otowi and on 06 Sept 2003, the beta activity was recorded as 129 pCi/L at Otowi and 145 pCi/L at White Rock. As noted earlier, the TSS concentrations at Otowi were 9850 mg/L on 25 Aug 2003 and 4710 mg/L on 06 Sept 2003.

The USGS data record for beta activity at Otowi exists between the years 1974 and 2001. In the filtered water samples, the maximum recorded beta activity was 7 pCi/L. Only one sample of suspended sediment was reported above 50 pCi/L, a sample of 200 pCi/L on 25 Jul 1991.

Gross beta activity was detected in all 9 samples of raw river water collected during the CDM pilot study, with results ranging from 5.6 to 319 pCi/L. The highest measured activities occurred during storm events, and the measured activity on days without reported rain was typically below 30 pCi/L. On 7 of the sampling episodes, a paired sample was collected from the effluent of the pilot treatment plant. Two of the treated water samples were below the detection limit, and all except one were below 5 pCi/L. The one with higher activity was taken during a time when the pilot plant was not operating correctly, including restarting of the filters and erratic flow through the filters [15]. The correspondence between raw and treated samples showed good beta activity removal in the pilot plant, with increasing removal as the raw activity increased. During the storm event on 12 Aug 2005, the raw beta activity was 200 pCi/L and the treated was 4.4 pCi/L, demonstrating nearly 98 percent removal.

Evidence that filtration can remove gross beta activity was also present in the LANL data record. During 7 sampling episodes, both filtered and unfiltered samples were collected and analyzed by LANL. The filtered sample was always below about 3 pCi/L. The overall trend was that the higher the activity in the unfiltered sample, the higher removal efficiency was achieved, with 98 percent removal efficiency occurring in the samples on 06 Sept 2003. It should be noted that a laboratory filter for determining filtered and unfiltered constituent concentrations is not as efficient as the process in the proposed BDD water treatment plant.

In summary, in nearly 350 samples collected over a 50-year period by 3 different organizations, only a handful of samples contained gross beta activity above the trigger activity of 50 pCi/L. The highest activity measurements occurred during storm events. In addition, the USGS data demonstrated higher activity in suspended sediments than in filtered water, and filtration done by the other two agencies demonstrated that filtration can be effective at removing beta activity in Rio Grande water to well below the 50 pCi/L level, with removal efficiency up to 98 percent.

Uranium

Uranium is sometimes reported in activity units (pCi/L) and other times in concentration units (µg/L), making comparison of data difficult. The LANL water quality database includes 43 samples for U-234 between 2000 and 2007. The only high activities were during the storm event on 25 Aug 2003, with activities of 108 and 88.8 pCi/L in duplicate samples at Otowi. Similarly, the only high reported activities for U-238 were activities of 111 and 92.9 pCi/L at the same location. The reported U-235/236 activities were much lower, with activities of 9.55 and 4.99 pCi/L in the same duplicate samples. It should be noted that the gross alpha particle activity was measured at 235 pCi/L, so the uranium activity can be seen as accounting for nearly all of the gross alpha particle activity during that storm event.

The USGS reported results for 136 filtered water samples were analyzed for uranium in the water column between 1974 and 2007. The mean concentration was 2.34 µg/L, with a maximum concentration of 6.1 µg/L. Thus, all samples were below the MCL of 30 µg/L for uranium.

CDM analyzed samples for uranium both in raw water and in the effluent from the pilot plant. Uranium was detected in all raw water samples, but the maximum measured concentration was 14.5 µg/L, well below the MCL. Three of the effluent samples were below the detection limit, and the remaining demonstrated removal efficiency of greater than 90 percent except one sample on 25 Oct 2005 (but CDM has reported that the pilot was not working properly at the time the sample was taken)[15]. The LANL water quality database also contains some filtered and unfiltered analyses. The data for the storm event on 06 Sept 2003 demonstrates 75 to 90 percent removal of uranium activity, and the C/CWTP process will be more effective at removing particle matter than laboratory filter paper.

The maximum concentration found in the Cañada Ancha sediments by the NMED was 5.98 μg/g, well below the regulatory limits.

In summary, the data collected for uranium concentrations were all below the MCL. Two samples measured on an activity basis were above 15 pCi/L, but it should be noted that the 15 pCi/L MCL does not apply to uranium. The uranium activity measurements by LANL, particularly the data on 25 Aug 2003, demonstrate that uranium activity contributes significantly to the total gross alpha particle activity. The data from the CDM pilot plant and from LANL analyses indicates that filtration is effective at removing uranium.

Plutonium

LANL analyzed 354 samples for Pu-239/240 between 1961 and 2007. None of the samples had an activity above 15 pCi/L. The median activity was 0.005 pCi/L. The highest reported activities were a series of 17 samples in 1962 and 1963 that had a reported activity of 2.22 pCi/L, one sample at Embudo on 29 Mar 1976 that had an activity of 2.76 pCi/L, and one sample during the storm event on 25 Aug 2003 that had an activity of 1.0 pCi/L, which was when high alpha and beta activity was measured.

CDM collected Pu-238 and Pu-239/240 and none were above the detection limit except one sample near the detection limit at 0.0002 pCi/L. The USGS water quality website contains data from 4 sampling episodes for selected radionuclides at the Otowi site. For Pu-238 and Pu-239/240, some samples were reported below the detection limit, whereas others were reported as a detection but so close to the detection limit that quantification was not possible.

The NMED report identifies Pu-238 and Pu-239/240 in the Cañada Ancha sediments. The maximum activity found were 0.0056 pCi/g of Pu-238 and 0.067 pCi/g of Pu-239/240. If this sediment were suspended in the water during a storm event such as that on 25 Aug 2003 (i.e., a TSS concentration near 10,000 mg/L), the activity in the water would be below 1 pCi/L.

Graf[13] summarized data from LANL Environmental Surveillance Reports from 1977 to 1988. At the Otowi gage, the Rio Grande water had a mean concentration of 0.0016 pCi/L of Pu-238 and 0.004 pCi/L of Pu-239/240 (17 samples). It should be noted that the mean activity was higher at Embudo, upstream of any LANL impact, with activities of 0.0103 and 0.0106 pCi/L for Pu-238 and Pu-239/240, respectively (18 samples). Upstream activities are due to global fallout of plutonium. The highest individual activities in the sample set were 0.090 pCi/L for Pu-238 and 0.130 pCi/L for Pu-239/240.

Plutonium activity in bed sediments in the Rio Grande were also summarized by Graf. At Otowi, the Pu-238 activity was 0.0003 pCi/g and the Pu-239/240 activity was 0.0106 pCi/g (mean of 16 samples). Graf makes the point that these measured activities in the sediments are about 3 orders of magnitude higher than the activities in the water column, indication a strong preference for adsorption onto solids.

If the bed sediments identified by Graf were suspended in the water at 10,000 mg/L, the activity of the plutonium due to suspended sediments in the water would be 0.003 pCi/L for Pu-238 and 0.106 pCi/L for Pu-239/240 based on the mean sediment activities at the Otowi station, or more than 100 times lower than the gross alpha activity of 15 pCi/L.

In summary, the substantial record of plutonium activities in the Rio Grande water and sediments indicates no samples that approached the regulatory limits. The highest activities (measured during storm events) were an order of magnitude below the regulatory limit, and the average activities were two or more orders of magnitude below the regulated limit.

Americium

LANL took 81 samples for analysis for Am-241 between 1975 and 2007. CDM took 5 additional samples during the pilot study. All samples taken by CDM and 32 samples collected by LANL were below the detection limit. In addition, the USGS water quality database contains 4 sampling episodes for Am-241 at the Otowi site. USGU reports that Am-241 was detected but not high enough to be quantified. No samples by any organization reached the level of 15 pCi/L; in fact, the highest concentration measured in any of these samples was 0.12 pCi/L taken on 25 Aug 2003, the day of the big storm event.

NMED measured Am-241 in the sediments along the Rio Grande. The highest measured activity was 0.026 pCi/g. Even if this sediment were suspended in the water at 10,000 mg/L, the activity would still be substantially below regulatory limits.

In summary, using data collected by LANL, USGS, NMED, and CDM, even including data collected during large storm events, the highest activity of Am-241 measured in Rio Grande water was more than 100 times lower than the gross alpha activity MCL.

Cesium

The water quality database from LANL contains 231 data points for Cs-137, collected between 1973 and 2007. Of these samples, the median value was 4 pCi/L and only 1 sample had a measured activity above 200 pCi/L, the value that corresponds to an equivalent dose of 4 mrem/yr in the SDWA. This excursion was 1200 pCi/L on 15 Sep 1987. Several facts lead to the probably that this analytical result was an error. First, the result more than 6 times higher than any other Cs-137 activity measured in the Rio Grande. Second, cesium, tritium, and plutonium were all measured at three locations on that day. The tritium and plutonium are consistent and low in all three locations, whereas the cesium was an order of magnitude higher at one location than at the other two. If the cesium were actually high at that location, either tritium or plutonium would also have been high. The data exhibits much higher variability prior to 1993, with consistently low values after that time. The variability in measured Cs-137 activity is shown in Figure 2. The decreased variability was likely due to improved analytical methods. The Cs-137 activity on 25 Aug 2003 and 6 Sept 2003, the days of the large storm events, were below detection limits, indicating that substantial increases in cesium activity during large storm events are not likely.

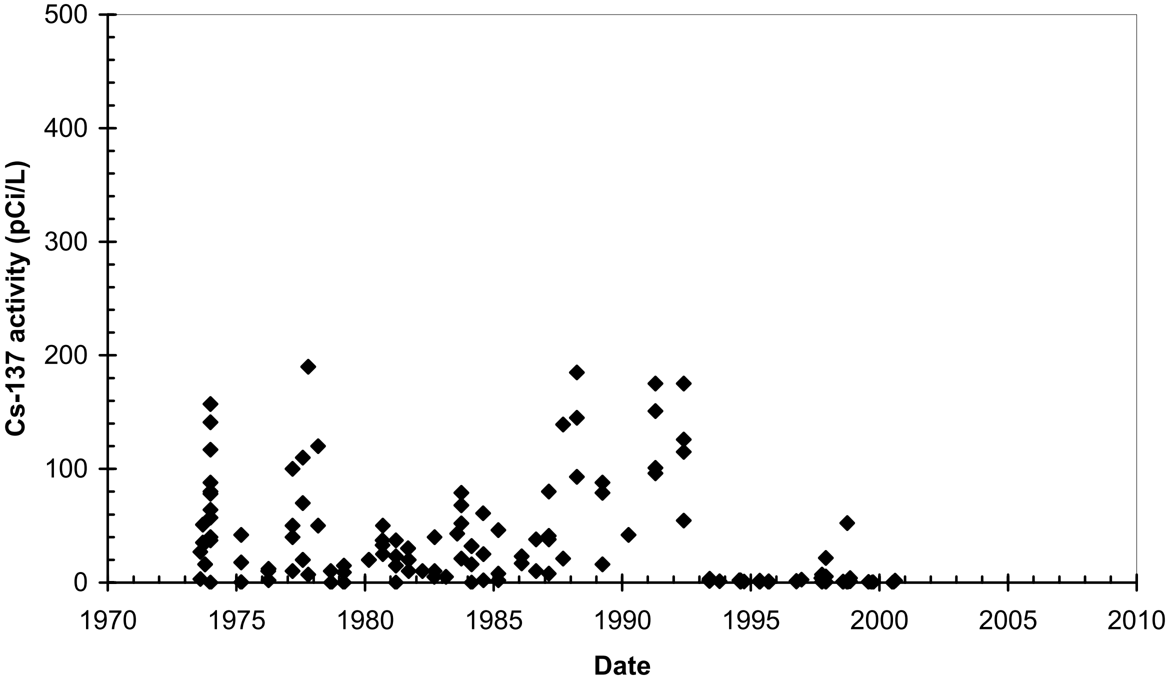

Figure 2 – Cs-137 Activity in Rio Grande Water

Figure 2 includes data both upstream and downstream of the proposed BDD intake site and the confluence of Pajarito Plateau canyons that drain LANL property. This data is representative of the Cs-137 activity in the Rio Grande in the vicinity of the proposed intake, but it does not distinguish between Cs-137 that may have originated from LANL property from that which may be present from other sources.

Five samples for Cs-137 were collected during the CDM pilot study, and all were below the detection limit. The USGS and NMED report Cs-137 concentrations in sediments along the Rio Grande. The USGS water quality database for Otowi contains 4 samples with a maximum activity of 0.13 pCi/g and the maximum activity found in the Cañada Ancha sediments by NMED was 0.98 pCi/g. If sediments containing these concentrations were suspended in the river water at a concentration of 10,000 mg/L TDS, the measured concentration in the river would be 9.8 pCi/L.

The Cs-137 activity that produces a 4 mrem/yr equivalent dose is continuous exposure at 200 pCi/L. In summary, sampling by LANL, USGS, CDM, and NMED show the activity in the Rio Grande to be consistently below that level.

Radium

River water sampling by the USGS between 1974 and 2003 resulted in 80 filtered-water sample analyses for Ra-226 at the Otowi gage. Seventy-seven of these samples were above the detection limit, but the average concentration was just 0.088 pCi/L, nearly 2 orders of magnitude below the limit of 5 pCi/L for combined Ra-226 and Ra-228. The maximum concentration measured in those samples was 0.67 pCi/L.

Ra-226/228 was also measured during the CDM pilot study. In the raw river water, 5 samples were below the detection limit and the remaining 4 samples ranged from 0.44 pCi/L to 11.7 pCi/L, with the highest activities occurring during storm events. All samples except one in the treated water were below the detection limit, and the remaining one was 0.59 pCi/L, nearly an order of magnitude below the MCL of 5 pCi/L.

In summary, the measured activity of Ra-226/228 has been substantially below the MCL, except in 2 raw water samples measured during the CDM pilot study. Corresponding treated water samples were below the MCL.

Strontium

The LANL water quality database contains data from 87 sampling episodes for Sr-90 in Rio Grande water. Of these, the median value was 0.45 pCi/L and only 2 were above the activity of 8 pCi/L that corresponds to the equivalent dose of 4 mrem/yr. The values of the two excursions are shown in Figure 3 in relation to the rest of the data set. The 1998 excursion occurred during a time when the TSS was measured at 9,312 mg/L, indicating a significant storm event. The reported activity of Sr-90 (a beta emitter) in the 1976 excursion is higher than the reported gross beta activity. LANL has stated that they believe high values such as the one measured in 1976 to be erroneous. Prior to 2000, Sr-90 analyses were conducted at an internal analytical laboratory at Los Alamos. Beginning in 2000, LANL began contracting strontium-90 analyses to offsite independent analytical laboratories. Overall data reliability and defensibility improved particularly with the improvements in the QA/QC data packages [16].

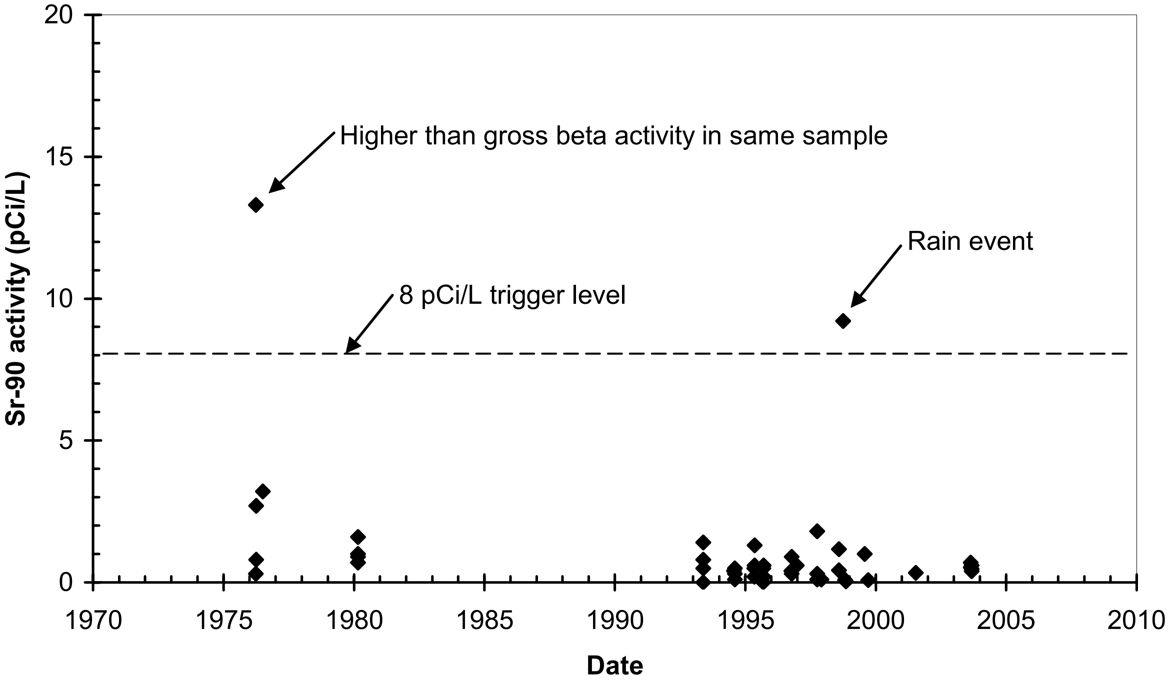

Figure 3 – Sr-90 Activity in Rio Grande Water

The USGS analyzed 4 samples for Sr-90 in 2000 and 2001. The highest activity measured by the USGS was 2.2 pCi/L. NMED measured Sr-90 in the sediments of the Rio Grande and the highest measured activity in the sediments at Cañada Ancha was 0.64 pCi/g. Even if the sediment were suspended in the water at 10,000 mg/L, the activity in the water would not reach the target maximum activity.

CDM analyzed samples for Sr-89 and Sr-90 during the pilot study. Sr-90 was detected in one of the five samples collected, with an activity of 39.7 pCi/L. CDM has stated that they consider this result anomalous because of its high value with respect to the rest of the historical record [15]. The CDM results also reported one detection of Sr-89. As shown in Table 2, however, the half-life of Sr-89 is 50 days (meaning half of the radioactivity will decay every 50 days, or more than 99 percent will decay per year). Thus, Sr-89 could only be present if there were a recent contamination of the river with a fresh source of Sr-89. Sr-89 is no longer present in global fallout, and there is no known continuing source of Sr-89. The result appears to be an erroneous value.

The relationship between Sr-90 and gross beta activity is significant. Other than storm events, the beta activity reported earlier has always been below 8 pCi/L since 2000, except for one value of 10.7 pCi/L reported on 26 Sept 2007 at Frijoles. That sample had a paired sample that had been filtered and was below the detection limit. The evidence reported thus far indicates that beta activity is high only during storm events, and that filtration is effective at removing beta activity to below the target maximum activity for Sr-90. In addition, elevated Sr-90 was not observed during the storm events of 25 Aug 2003 and 06 Sept 2003, when high gross alpha and beta activity was observed.

In summary, more than 100 samples have been collected for Sr-90 in Rio Grande water. All except 3 have been below the target maximum activity of 8 pCi/L. The fact that these 3 samples are inconsistent with the historical record and rain patterns suggests that the results may have been the result of analytical error.

Tritium

The LANL water quality data for the Rio Grande contains 262 samples for tritium between 1967 and 2005. The highest measured value was 6500 pCi/L, measured in the 1970s, and the median value was 300 pCi/L. Tritium activity has steadily decreased over time, as shown in Figure 4. After 1986, tritium activity has consistently been below 700 pCi/L. All samples after 2000 are below the detection limit. Samples collected during the CDM pilot study were in the range of 20 pCi/L and samples collected by the USGS at the Otowi gage have ranged from 20 to 50 pCi/L.

Tritium occurs naturally due to cosmic radiation interacting with gases in the upper atmosphere. Additional tritium has entered the environment due to global atmospheric nuclear weapons testing. Tritium is widely present in surface waters at an activity of about 10 to 30 pCi/L [17].

The tritium activity that produces a 4 mrem/yr equivalent dose is continuous exposure at 20,000 pCi/L. In summary, tritium has never been measured near that level, and current activity is about 3 orders of magnitude below that level.

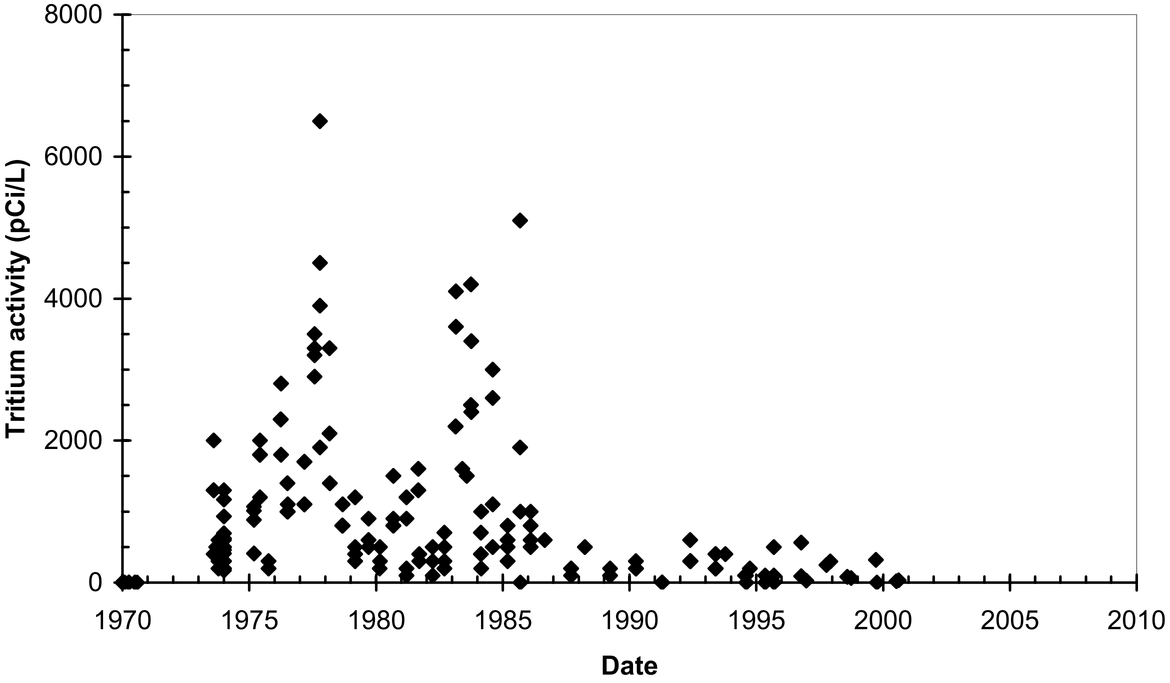

Figure 4 – Tritium Activity in Rio Grande Water

Chromium

Samples were collected for total chromium during the CDM pilot study. The concentrations were generally low, ranging from 2 to 14 μg/L in the raw river water and from below the detection limit to 6 μg/L in the pilot plant effluent. These concentrations are low compared to the MCL for chromium, which is 100 μg/L. Data for chromium concentrations in the river water are not available from the other agencies.

Perchlorate

CDM collected 4 samples for perchlorate from Rio Grande water during the pilot study. All were below 0.1 μg/L, and the one sample in the pilot plant effluent was 0.08 μg/L. These results are all below the target maximum concentration of 6 μg/L (note, no Federal or State MCL exists for perchlorate in drinking water).

Polychlorinated Biphenyls

CDM analyzed 9 samples from the Rio Grande and 7 samples from the pilot plant effluent for PCBs. All were below the detection limit.

Edwards [18] recently completed a professional project (i.e., masters thesis) at the University of New Mexico that examined the issue of PCBs in the Rio Grande. All available data on PCBs in the river from all known sources were tabulated in an appendix. PCBs have been detected in water, fish tissues, and sediments within the river system (both upstream and downstream of LANL), and in canyons on LANL property. PCB concentrations in water samples in the Rio

Grande have never exceeded the drinking water MCL of 0.5 µg/L. The highest PCB concentration was a sample in Colorado collected by the USGS in 1979 that was measured at 0.1 µg/L using the Araclor method. More recent analyses, conducted as a joint NMED/LANL effort between 2002 and 2005, have detected concentrations averaging 0.00132 µg/L, with the highest measured concentration being 0.0116 µg/L. This concentration is less than one-tenth of the drinking water MCL.

NMED has a water quality standard for PCBs of 0.00064 µg/L that is intended to be protective of human health related to consumption of fish that live in the river. Measurements have exceeded this level, and PCBs have also been measured in fish tissues and sediments, so segments of the river have been listed as impaired. In addition, canyons within LANL property have higher concentrations of PCBs and have been listed as impaired.

In summary, sections of the Rio Grande have been listed as impaired by the NMED because the PCB concentration has the potential to impact humans that eat fish that live in the water. However, concentrations of PCBs measured in the water column have always been lower than drinking water standards.

Pharmaceutical and Personal Care Products and Endocrine Disruptors

PPCPs and EDCs enter natural waters via the effluent discharge from municipal wastewater treatment plants. PPCPs can enter wastewater by being ingested by humans and then being excreted with waste, or when people flush unused or excess medication down the toilet. Although some PPCPs can be degraded during the wastewater treatment process, some pass through the plant into the wastewater effluent and then into the receiving water. The potential for PPCPs to be present in the water supply has been the subject of recent media coverage, and people are concerned whether PPCPs and EDCs represent new types of contaminants in drinking water.

A national reconnaissance of 95 organic compounds in139 rivers across the United States was conducted by the USGS in 1999-2000 [19]. Modern analytical methods are capable of detecting very low concentrations of organic compounds, which increases the likelihood that contaminants will be found. PPCPs were found in 80 percent of the rivers. Concentrations were generally very low. For instance, the highest measured concentration of ibuprofen (Advil) in that study was 1 µg/L. Lifetime ingestion of water (2 L/day for 70 years) with this concentration would result in a total lifetime intake of 51 mg – about one-fourth of the dose in a single 200-mg Advil tablet. The effect of long-term exposure to trace doses of pharmaceuticals or synergistic effects of multiple pharmaceuticals is not known at this time and is currently being investigated by the research community. To date, research has not detected an impact on human health from the trace concentrations of pharmaceuticals being found in drinking water.

NMED has conducted an initial surveillance of the presence of pharmaceutical residues in waters of the state. In general, the frequency of occurrence of drug residues in New Mexico rivers appears to be less than in other locations. Of the 23 surface water samples collected, only 4 contained drug residues. The only pharmaceutical detected near or upstream of the Buckman diversion site was the anti-depressant medication amitriptyline, which was detected in the Rio Grande at Buckman Crossing at 30 ng/L [20]. At a rate of ingestion of drinking water of 2 L/day for 70 years, this concentration corresponds to a lifetime intake of 1.5 mg. As a point of comparison, typical adult doses of amitriptyline for treatment of depression range from 40 to 150 mg daily [21]. In other words, if the treatment facility were unable to remove amitriptyline, the intake by a resident of Santa Fe over an entire lifetime would be 100 times less than a single day's dose when taken for medical purposes.

One reason for the lack of pharmaceutical residues in the Rio Grande is the lack of metropolitan areas upstream of Santa Fe. Overall, the impact of wastewater discharges on the flow of the Rio Grande is relatively small. For instance, the NPDES permits for 2 of the larger communities discharging wastewater effluent into the Rio Grande upstream of Santa Fe list the design flow for the Española wastewater treatment plant as 1.6 mgd [22] and the Alamosa, CO wastewater treatment plant as 2.6 mgd [23]. In contrast, the average flow of the Rio Grande at the Otowi Gage is over 900 mgd [13]. Another possible reason cited for the low concentrations of pharmaceuticals in New Mexico surface waters is that the combination of shallow rivers and intense sunlight may lead to the photolytic degradation of pharmaceutical residues [20].

In summary, only limited information is available about the potential presence of PPCPs in Rio Grande water at the Buckman diversion site, but the potential for contamination is lower than in many other rivers. Nationally, pharmaceuticals have been found in many rivers at low concentrations. Human health impacts from exposure at these low concentrations has not been documented but is being studied.

6. Impact of the Los Alamos Canyon on the Rio Grande

Historically, flow of water and sediment from the Los Alamos Canyon has had relatively little impact on the overall water and sediment loads in the Rio Grande. Figure 5 reproduces two figures from Graf [13] that show various contributions to the water and sediment load in the river. The Los Alamos Canyon is normally a dry arroyo, and only discharges to the river during spring runoff and during storm events. According to the data in Figure 5, the Los Alamos Canyon contributed 0.008 percent of the long-term average water flow in the Rio Grande near the proposed diversion. Similarly, it contributed 0.1 percent of the sediment load to the river at that location. Thus, a large dilution effect from the main stem of the river reduces the impact of contamination originating from Los Alamos Canyon on an annual average basis.

The Cerro Grande Fire in May 2000 burned several thousand acres of forest in and around Los Alamos. Following the fire, increased runoff was noted and concern was raised about potential for increased transport of contaminants to the Rio Grande. Several studies have been undertaken to evaluate this impact. NMED [24] found increased contaminant transport in Lower Pueblo Canyon, a canyon that joins the Los Alamos Canyon before it intersects the Rio Grande. Peak flows in Pueblo Canyon immediately after the fire have averaged about 11 times the pre-fire peak flows. Additionally, LANL found that total runoff from Pueblo Canyon in the years 2001 to 2003 were 2 to 4 times greater than the pre-fire runoff amounts [25]. Even with an order of magnitude increase in water and sediment transport, the Los Alamos Canyon is still a small fraction of the total flow of the Rio Grande. An independent study commissioned by NMED after the fire found that the risk from releases to surface water were within acceptable levels

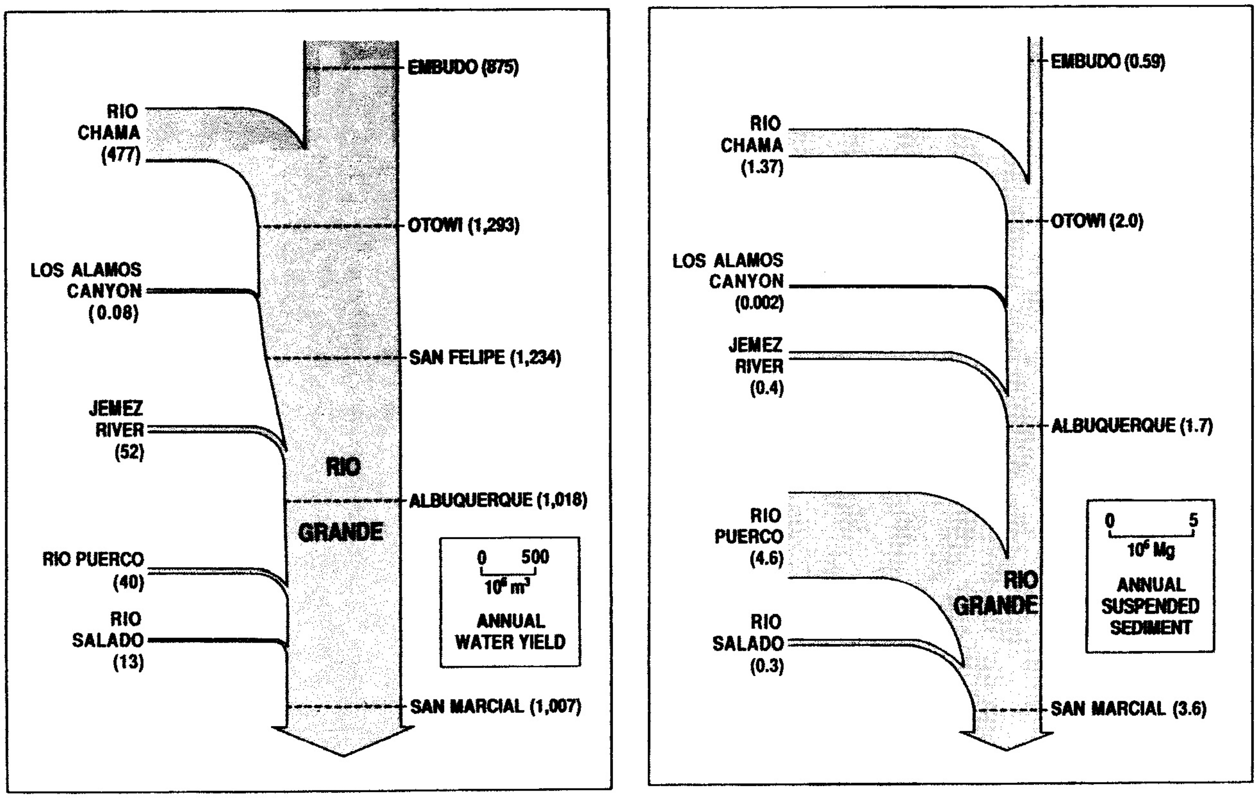

Figure 5 – Water and Suspended Sediment Loads in the Rio Grande (from Graf)

established by EPA, and that the greatest risk was from eating fish [26]. Other studies after the fire have come to similar conclusions [27-29]. Nevertheless, protecting source water quality is a recognized component of overall water treatment practices [30], and efforts to minimize transport of contaminants to the river are prudent. In this regard, the NMED report made a number of recommendations to stabilize conditions in the canyon and reduce the downward movement of contaminants.

While the affect of the Los Alamos Canyon on river flows may be minimal on an annual average basis, the same clearly cannot be said during storm events. Localized heavy rain typical of New Mexico monsoons can lead to large contributions of water and sediment to the river from small areas. Increased contaminant concentrations in the river may be possible during storm events and was reflected in the data record presented earlier in this report. It addition, NMED [31] has reported an instance where high flows in the Los Alamos Canyon combined with below-average flow in the main stem of the Rio Grande could produce Pu-239/240 activities in the Rio Grande above the MCL for gross alpha activity. Using measured Pu-239/240 activities in Los Alamos Canyon during a storm event, NMED calculated a maximum activity of 287 pCi/L in Rio Grande water and activity remaining above 15 pCi/L for over 4 hours, based on a mass balance at the point of confluence of the Los Alamos Canyon and the Rio Grande. The storm event suspended a high concentration of sediment in the storm flow (up to 66,782 mg/L). Plutonium is strongly associated with sediments, and the Pu-239/240 activity and suspended sediment concentrations measured during the event suggest the sediments were contaminated with Pu-239/240 at an activity of about 6 pCi/g. LANL has measured Pu-239/240 contamination as high as 4.1 pCi/g in the sediments of Los Alamos Canyon and 15.5 pCi/g in Pueblo Canyon [10].

Thus, while the Rio Grande is an acceptable source water on an annual average basis, it would be prudent to try to minimize the impact of large storm events on water treatment operations. Options include efforts to minimize the transport of contaminants from LANL property to the Rio Grande and operational procedures to cease diversion of water into the C/CWTP when significant storm events are impacting water quality in the Rio Grande (measured as high turbidity).

7. Chemistry of the Contaminants

The chemical properties of a contaminant are key considerations in determining the ability of a water treatment process to remove the contaminant. In this section, the basic chemical properties of each contaminant are briefly reviewed from the perspective of the properties that will influence removal by a water treatment process.

It is important to determine the speciation of each contaminant in the actual conditions of the Rio Grande to assess treatment efficiency. For instance, removal can be affected by the solubility of any compound containing the contaminant, and treatment efficiency can be affected by whether they exist as ions or neutral complexes. To provide an accurate and detailed understanding of the chemistry of the contaminants under conditions representative of Rio Grande water, the water quality of the Rio Grande was modeled using Visual MINTEQ (version 2.53) [32]. Concentrations of N, K, Ca, Mg, Cl, HCO_3, SO_4, F, and SiO_2 were based on averages of USGS water quality data from 2000 to 2007 at the Otowi site. The pH was 8.2 based on USGS data and 2.8 mg/L of dissolved organic carbon was included in the model using the Gaussian parameters. Activity coefficients were modeled using the Davies equation, oversaturated solids were allowed to precipitate, and several solid phases (Quartz, Aragonite, Chalcedony, Calcite, and Dolomite) were excluded from the model calculations to allow the model to accurately predict the measured aqueous concentrations of the species associated with those minerals. To determine contaminant speciation, concentrations of each were included in the model input at a concentration of 10^{-8} mol/L. This concentration was used to represent a low concentration (i.e., less than 1 μg/L of each contaminant).

Actinides (Uranium, Plutonium, and Americium)

Uranium, plutonium, and americium have very similar chemistry with respect to aqueous speciation and water treatment, so they will be discussed together. Each exists in 3 or 4 oxidation states. Uranium can exist as U(IV), U(V), and U(VI), plutonium can exist as Pu(III), Pu(IV), Pu(V), and Pu(VI), and americium can exist as Am(III), Am(IV), Am(V), and Am(VI). The U(IV) oxidation state is predominant under reducing conditions and U(VI) is the predominant oxidation state under oxidizing conditions such as those present in the Rio Grande. Am(III) is the only oxidation state of americium observed in nature, but plutonium may exist as either Pu(V) and Pu(VI) in natural waters [9].

Based on the speciation modeling, each of these radionuclides forms hydroxide and carbonate complexes in aqueous solution. Modeling of aqueous chemistry of the Rio Grande indicated that uranium is entirely complexed, with over 99 percent of U(VI) present as $Ca_2UO_2(CO_3)_{3\,(aq)}$ and $CaUO_2(CO_3)_3^{-2}$, and the remaining less than 1 percent present as $UO_2(CO_3)_2^{-2}$ and $UO_2(CO_3)_3^{-4}$. MINTEQ predicts that possible mineral phases are UO_3, $UO_3{\cdot}3H_2O$, $UO_2(OH)_2$, and UO_2CO_3, but that the concentrations present in the Rio Grande will not be limited by solubility of these minerals.

Regardless of whether it is present in the Pu(V) or Pu(VI) oxidation state, plutonium is completely complexed in aqueous solution in both oxidation states. When present as Pu(VI), the predominant species are $PuO_2(CO_3)_2^{-2}$ and $PuO_2CO_{3\,(aq)}$, with minor amounts of $PuO_2(CO_3)_3^{-4}$, $PuO_2(OH)_{2\,(aq)}$, and PuO_2OH^+ (less than 1 percent each). Solid phases include $PuO_2(OH)_2$ and PuO_2CO_3. When present as Pu(V), the main complexes are $PuO_2CO_3^-$ and PuO_2^+ with small amounts of $PuO_2OH_{(aq)}$ and $PuO_2(CO_3)_2^{-3}$. The solubility of the solid phases will not limit the concentration of plutonium in the Rio Grande at the concentrations that have been noted in the river.

The primary species of americium is Rio Grande water, in order of predominance, are $AmCO_3^+$, $Am(CO_3)_2^-$, $Am(OH)_2^+$, and $AmOH^{+2}$. Solid phases that might exist include $Am(OH)_3$, $Am_2(CO_3)_3$, AmF_3, and $AmOHCO_3$. Americium is considerably less soluble than uranium or plutonium under conditions that exist in the Rio Grande, and the maximum concentration of 4.6×10^{-9} mol/L would be controlled by $AmOHCO_3$, known as orthorhombite.

Substantial evidence exists that indicates that uranium, plutonium, and americium bind strongly to soil. Graf [13] noted that the concentration of uranium in sediments in the Rio Grande were 1000 times greater than in the aqueous phase. This strong preference for partitioning from water onto solid phases is described in other literature. Allard and Rydberg [33] summarized data from a number of sources and found partition coefficients for plutonium to be about 10^5 mL/g or higher (in a soil-water system at equilibrium, the amount of plutonium on the soil will be 10^5, or 100,000, times the amount in the water). Other literature also notes that actinides strongly adsorb to soil and sediments [9, 34]. All actinides adsorb strongly to soil, and it has been found that the strength of attraction decreases in the order Pu>Am>U [33]. Because actinides attach preferentially to sediments, any treatment process that removes particles will be an effective treatment process for uranium, plutonium, and americium.

Cesium

Cesium is a Group 1A, or alkali, metal and exists only in the Cs(I) oxidation state. As a result, it would be expected to have properties more similar to other Group 1A metals such as sodium or potassium than to the actinides. The water quality modeling by Visual MINTEQ supports this conclusion. Modeling predicts that cesium participates in very little complexation, and over 99 percent of the cesium in solution is present as the cation Cs^+.

The sorption of cesium to sediments is reported to be dependent on the type of sediment [35]. The ranking of minerals with respect to the amount of cesium sorbed has been reported as illite > mica > vermiculite = smectite > kaolinite. Partition coefficients for the sorption of cesium to mica are in the range of 10^4 mL/g. The variable behavior of cesium in the presence of sediments indicates that it may not necessarily be removed in a water treatment process that removes particles, such as coagulation/filtration. Removal will be influenced by the type of mineralogy present. In some cases, the binding of cesium to sediments is so strong that it has been effectively used as a tracer for soil erosion [13].

Cesium-137 is primarily present in the environment as a fission product of nuclear reactors and nuclear weapon detonations. The vast majority of Cs-137 released to the environment has been from global atmospheric nuclear weapons testing [35]. Cesium tends to enter the same biological pathways as potassium.

Strontium

Strontium is a Group 2A, or alkaline earth, metal and exists only in the Sr(II) oxidation state. Its chemical behavior is more similar to other Group 2A metals such as calcium than to actinides such as uranium. Strontium exists primarily as the Sr^{2+} ion with small amounts of carbonate and sulfate complexes. At the conditions in the Rio Grande, MINTEQ predicts about 92.7 percent of the strontium in solution is present as Sr^{2+}, 4.5 percent as $SrSO_{4\,(aq)}$, 2.2 percent as $SrHCO_3^+$ and 0.6 percent as $SrCO_{3\,(aq)}$.

Strontium can adsorb to clays, but the effect is not as strong as with actinides. The strength of adsorption is affected by both the type of sediment and the species in solution. The primary species participating in adsorption of strontium to a clay consisting of a mixture of illite and kaolinite has been identified in one study [36] as Sr^{2+} and $SrCO_{3\,(aq)}$. The $SrCO_{3\,(aq)}$ adsorbed more strongly to clay with a partition coefficient of 2180 mL/g compared to the partition coefficient of 34.5 mL/g for Sr^{2+}. As noted above, about 92.7 percent of the strontium is predicted to be present as Sr^{2+}, indicating that adsorption to clay may not be particularly strong in conditions present in the Rio Grande. However, Cole et al. [36] show that the fraction of $SrCO_{3\,(aq)}$ increases dramatically with increasing pH, suggesting that increased partitioning of strontium to particles may occur if the pH is raised in the treatment facility.

Tritium

Tritium is an isotope of hydrogen with 2 neutrons. It replaces hydrogen wherever hydrogen is present, and therefore in aqueous systems the prevalent location for tritium is as a replacement for one of the hydrogen atoms in a water molecule. In other words, a tritiated water molecule exists as HTO instead of H_2O. Tritium will move and behave in the environment just as water does.

Chromium

Chromium commonly exists in either the Cr(III) or Cr(VI) oxidation state in natural waters. While Cr(III) is an essential human nutrient, Cr(VI) is a heath concern. In the conditions present in the Rio Grande, MINTEQ predicts that chromium in the Cr(III) oxidation state will be present almost entirely as $Cr(OH)_{3(aq)}$, with the remaining 1.5 percent present as $Cr(OH)_2^+$. Chromium in the Cr(VI) oxidation state is predicted to be 78 percent CrO_4^{2-}, 21 percent $CaCrO_{4(aq)}$, and 1 percent $HCrO_4^-$. Both Cr(III) and Cr(VI) are capable of partitioning strongly to soil, clays, sands, and iron and manganese oxides [37].

Perchlorate

Perchlorate is a specific anionic chemical species with the chemical formula ClO_4^-. Perchlorate salts are relatively soluble.

Polychlorinated Biphenyls

PCBs are a class of organic compounds with a similar structure. The primary structure consists of two aromatic rings connected by a single carbon bond. Each aromatic ring can contain between 0 and 5 chlorine atoms, resulting in theoretically 209 different congeners. Physicochemically, PCBs are uncharged, nonpolar, hydrophobic organic chemicals with relatively low volatility, low reactivity, and low solubility in water.

Pharmaceutical and Personal Care Products and Endocrine Disruptors

PPCPs and EDCs are large classes of chemicals that are used for medical, personal, or household purposes. They include over-the-counter medicines, prescription medicines, hormones, detergents, cosmetics, antimicrobials, insect repellants, and other chemicals. PPCPs are organic chemicals with a wide range of physicochemical properties that depend on the intended use of the chemical. As a result, it is not easy to characterize specific chemical properties that can be taken advantage of for treatment purposes.

8. Removal Efficiency of Water Treatment Processes

The process train for the proposed C/CWTP consists of coagulation with ferric chloride, flocculation, sedimentation, membrane filtration, ozonation, and granular activated carbon adsorption. One of the primary functions of the new water treatment plant is to remove particles, and the proposed coagulation-flocculation-sedimentation-membrane filtration process will be excellent at removing particles. As a result, it will also be excellent at removing any contaminants that are adsorbed to particles.

Concern was raised in the community that the pore size of the membrane filters would be too large and would allow the passage of colloidal particles with adsorbed actinides. Colloidal particles are so small that they do not settle out of suspension no matter how long the suspension sits. However, the water treatment profession has extensive experience designing processes to remove small colloids. For instance, viruses with a diameter as small as 0.025 μm can be effectively removed by granular media filters that have a nominal pore dimension of 50 to 75 μm. The process for accomplishing this is pretreatment of the water with the coagulation/flocculation process. The main purpose of the coagulation/flocculation process is to assist subsequent processes with removal of particles that would not otherwise be removed. The coagulant preconditions the particles, and the flocculation process aggregates the particles into larger masses. The specified nominal pore size of the membrane filters in the C/CWTP plant is 0.1 μm, more than 100 times smaller than the pore size in granular media filters. Thus, the coagulation/filtration process at the C/CWTP will be effective for removing a wide range of colloids and particles, including colloids smaller than the pore size of the membrane.

The purpose and capabilities of each process and chemical is shown in Table 8. The ability of the proposed C/CWTP to remove specific contaminants is detailed in this section, tabulated by

Table 8 – Primary Purpose of Individual Processes in the C/CWTP.

Process	Function
Coagulation with ferric chloride	Neutralizes charge on particles to facilitate removal in subsequent processes, will also adsorb various dissolved contaminants.
Flocculation	Aggregates particles into larger floc to facilitate removal in subsequent processes (no removal of contaminants occurs within this process directly).
Sedimentation with plate settlers	Removes 90-95 percent of particles.
Membrane filtration	Removes essentially 100 percent of particles above the pore size of the membranes. Particles smaller than the pore size can be effectively removed if they have been preconditioned with a coagulant.
Ozone	Applied as a preoxidant and before GAC adsorption to break down organics to facilitate adsorption on the granular activated carbon and for disinfection.
Granular activated carbon	Adsorbs organic contaminants.
Chlorine	Disinfection.
Caustic soda	Raises pH (no removal of contaminants).

parameter. Following the discussion of removal capabilities for individual contaminants, two additional unit processes are discussed. These two processes, ion exchange and reverse osmosis, are considered best available technology for many inorganic and radiological contaminants. The BDD board requested additional information regarding these processes and their applicability within the C/CWTP process train, should additional treatment be warranted at some point in the future.

Actinides (Uranium, Plutonium, and Americium)

As noted earlier, substantial evidence indicates that uranium, plutonium, and americium bind strongly to soil. Because of this behavior, any treatment process that removes particles will be an effective treatment process for uranium, plutonium, and americium. The coagulation/ flocculation/sedimentation/membrane filtration process in the proposed C/CWTP will have excellent particle removal properties, and thus will effectively remove uranium, plutonium, and americium if they are present.

The Radionuclides Rule [1] lists coagulation/filtration, ion exchange, lime softening, and reverse osmosis as a best available technology for the removal of uranium. The CDM pilot study [12] also demonstrated that the proposed treatment process is effective at removing uranium. As noted earlier, plutonium and americium bind more strongly to sediments than uranium, so any process capable of removing uranium will also remove plutonium and americium. Recent studies have also noted the effectiveness of the coagulation/filtration process for removing uranium, plutonium, and americium [38, 39].

In addition to the effectiveness of the treatment process, it was noted earlier in this report that many samples have been taken in the Rio Grande water and sediments, and in no cases have the measured activities and concentrations of uranium, plutonium, and americium been greater than the MCLs. The low concentrations present, along with the effectiveness of the proposed treatment process, indicate that uranium, plutonium, and americium are not contaminants of concern for the C/CWTP.

The Institute for Energy and Environmental Research has advocated a new MCL for actinides of 0.15 pCi/L, which is 100 time lower than the current MCL for alpha particles [40]. It does not appear that EPA intends to set an MCL for actinides in the near future. EPA periodically publishes a contaminant candidate list (CCL) to prioritize research and data collection efforts to assist in the determination of whether a contaminant should be regulated in the future [3]. Generally, many years pass between identification of a contaminant for potential regulation on the CCL, and actual promulgation of a regulation. The most recent CCL was released in February 2008. Actinides are not on that list. Regardless of the potential for a separate MCL for actinides at 0.15 pCi/L, it does not appear that the C/CWTP would have trouble meeting such an MCL. The only instances in the last 30 years of plutonium activities in the Rio Grande above that level occurred on 25 Aug 2003 and 06 Sept 2003, the two storm events discussed earlier this report. Americium has never been measured above that activity in the Rio Grande.

Cesium

The removal of cesium in water treatment facilities has been the subject of a number of studies. In 1951, Straub et al. [41] found that more than 90 percent removal of cesium could be accomplished by the addition of 100 mg/L of clay. Coagulation with either alum or ferric chloride was also effective at removing cesium. More recently, however, a study at a treatment plant in Sweden found almost no removal of cesium by the coagulation/filtration process, even though the process effectively removed uranium and plutonium [39]. Baeza et al. [38] also reported almost no cesium removal in a standard coagulation/filtration process that was effective for removing americium. The literature suggests that the removal of cesium by a coagulation/ filtration process depends on the presence of specific clays or sediments that sorb cesium, and that the process may be enhanced by the addition of appropriate clay materials to the coagulation process.

As a monovalent cation, cesium would be effectively removed by ion exchange or reverse osmosis. Crittenden et al. [42] report that cation exchange resins would have good selectivity for cesium, and 99.8 percent removal of cesium in a cation exchange column as been reported as early as 1956 [43].

It should be noted, however, that the measured activity of Cs-137 in the Rio Grande has been relatively low. The highest measured activity prior to 1993, except for one sample, has been less than 200 pCi/L, the level that corresponds to 4 mrem/yr. Since 1993, the measured activities have been substantially lower, at least 1 to 2 orders of magnitude below the target maximum activities. During the storm events measured by LANL in 2003 and CDM in 2005, the Cs-137 activity was below the detection limit. Since the measured concentrations are low compared to the regulatory limit for cesium, treatment should not be required in the proposed C/CWTP. Although currently unnecessary, an additional process such as ion exchange or reverse osmosis could be added and used on intermittent basis if cesium became a concern in the future.

Radium

The best available technologies for combined radium-226/228 removal listed in the Radionuclides Rule are ion exchange, reverse osmosis, and lime softening. Co-precipitation with barium sulfate has also been identified as an effective radium removal strategy.

The levels of radium measured in Rio Grande water have consistently been low, with the exception of storm events during the CDM pilot study. The association with storm events, coupled with the effectiveness of the pilot facility for removing alpha and beta activity, suggests that the treatment process will effectively remove radium to below the MCL. When paired samples were collected, the CDM pilot study was able to remove radium from 5.9 pCi/L to less than the detection limit (2 pCi/L). Although currently unnecessary, an additional process such as ion exchange or reverse osmosis could be added and used on intermittent basis if radium became a concern in the future.

Strontium

As noted earlier, strontium is present in aqueous solution primarily as the divalent cation Sr^{2+}. Thus, it has properties similar to calcium, forming relatively insoluble sulfates and carbonates, but not binding strongly to soil. As a result, strontium is not as well removed by the coagulation-filtration process as the actinides are.

The removal of strontium has been examined in prior studies. Gafvert et al. [39] examined the removal of strontium in a treatment plant using both alum and ferric chloride coagulants prior to flocculation, sedimentation, and rapid granular filtration. The process was effective at removing uranium, plutonium, and other actinides, but was not effective at removing cesium, strontium, or radium. The plant in that study, however, was treating a low turbidity water (influent = 0.8 NTU) and used a low pH during coagulation (6.0 for alum, 5.2 for ferric chloride), so the conditions might not be representative of the Rio Grande and C/CWTP.

Laboratory studies were done in the 1950s to evaluate strontium removal by coagulation and filtration [41]. Jar testing demonstrated that the addition of 1000 mg/L of clay soil removed only about 25 percent of the strontium, indicating that strontium does not partition strongly to solids. The authors noted, however, that their mixing conditions greatly affected the results for some of the other radionuclides tested. Coagulation produced varied results depending on conditions, but the best conditions occurred with higher initial turbidity and the addition of sodium carbonate. Nonetheless, the maximum strontium removal observed was about 20 percent. Excellent removal of strontium was accomplished by the addition of calcium hydroxide and sodium phosphate at pH values above 10. At these conditions, more than 90 percent of the strontium could be removed. A survey of 50 operating water treatment plants in the 1950s demonstrated that plants using conventional coagulation with aluminum or ferric salts achieved between 10 and 31 percent strontium removal [44]. The addition of lime increased removal to up to 75 percent. The addition of soda ash in addition to lime increased the removal to up to 85 percent. Subsequent research demonstrated that strontium can be effectively removed by lime softening [43]. Recently, a study demonstrated that sodium carbonate softening at a pH of 10.3 removed strontium with a median removal efficiency of 99 percent [45].

The levels of strontium measured in Rio Grande water have consistently been low, with the exception of three samples, two of which were during storm events. The association with storm events, coupled with the effectiveness of the pilot facility for removing alpha and beta activity, suggests that the treatment process will effectively remove strontium to below the MCL. It is unlikely that additional treatment for strontium would be required, but if it is, a temporary modification to the treatment such as a pH adjustment, may be appropriate during high turbidity events. Although currently unnecessary, an additional process such as ion exchange or reverse osmosis could be added and used on intermittent basis if strontium became a concern in the future.

Tritium

HTO is indistinguishable from H_2O by any water treatment process used at a municipal scale. As a result, none of the technologies in the proposed BDD treatment plant, nor any possible replacement or additional process, will have any affect on the removal of tritium.

However, measured activities of tritium in recent years in the Rio Grande have ranged from 20 to 50 pCi/L, and the activity as which tritium would exceed the 4 mrem/yr limit for beta emitters is 20,000 pCi/L. Since the measured activities are approximately 1000 times lower than the regulatory level, it does not appear that tritium is a contaminant of concern for the C/CWTP.

Chromium

EPA lists coagulation/filtration, lime softening, ion exchange, and reverse osmosis as best available technology for total chromium removal. The proposed C/CWTP includes the coagulation/filtration process, and therefore contains the best available technology for removing chromium.

It should also be noted that the measured concentrations of chromium in the source water were consistently below the MCL. Therefore, it does not appear that chromium will be a contaminant of concern for the C/CWTP.

Perchlorate

Perchlorate is the one contaminant discussed in this report that is included on EPA's contaminant candidate list, which indicates that EPA is evaluating whether to develop an MCL for perchlorate in the future. Although not currently regulated by the EPA, the State of California has recently established an MCL of 6 μg/L for perchlorate. California lists biological fluidized bed reactors and ion exchange as best available technology for perchlorate. Because perchlorate is an ionic species, reverse osmosis would also be an effective treatment technology.

Since the measured concentrations are low compared to the potential regulatory limit for perchlorate, treatment should not be required in the proposed C/CWTP. Although currently unnecessary, an additional process such as ion exchange or reverse osmosis could be added if perchlorate became a concern in the future.

Polychlorinated Biphenyls

EPA lists granular activated carbon as best available technology for PCB removal. Since the proposed C/CWTP includes this process, it will contain the best available technology for removing PCBs.

It should also be noted that the measured concentrations of PCBs in the source water have consistently been below the MCL. Therefore, it does not appear that PCBs will be a contaminant of concern for the C/CWTP.

Pharmaceutical and Personal Care Products and Endocrine Disruptors

As noted in the chemistry section of this report, PPCPs and EDCs potentially have a wide range of physicochemical characteristics. As a result, it is not possible to specify a single treatment process that can reliably remove all PPCPs, with the possible exception of high-pressure (i.e., seawater) reverse osmosis. However, recent studies have been collecting data on the treatment efficiency of various common water treatment processes for classes of PPCPs with similar physicochemical properties.

The coagulation/filtration process would not be expected to be very effective for removal of most PPCPs because this process is typically not effective for soluble organic chemicals. A recent study [46] has supported this conclusion. Processes present in the C/CWTP process train that may be effective for various PPCPs include application of ozone at multiple stages for oxidation, adsorption with granular activated carbon (GAC), and final oxidation/disinfection chlorine.

Snyder et al. [46] found that GAC is effective for some classes of PPCPs. Charged species like ibuprofen were poorly removed by powdered activated carbon (less than 20 percent removal) and had short bed lives with GAC, but uncharged polar compounds like benzo(a)pyrene were effectively removed. Oxidation with chlorine was not very effective (less than 20 percent removal) for many compounds, but ozone was effective (greater than 95 percent removal with 2 minutes contact time) for most PPCPs. The proposed C/CWTP will have 5 minutes of ozone contact time at the maximum flowrate and greater contact time at lower flowrates.

The PPCP detected in the Rio Grande water near the diversion site was amitriptyline. The study reported above did not include that particular PPCP in the list of compounds being examined, so a direct assessment of the removal efficiency for that compound is not possible. However, based on structural characteristics, amitriptyline is most similar to carbamazepine, which was included in the study. Both are tricyclic compounds with two aromatic rings connected by a nonaromatic ring and include some amine functionality. Snyder et al. [46] found 50 to 80 percent removal of carbamazepine with activated carbon and greater than 95 percent removal with ozone. Since the proposed C/CWTP includes both ozone and GAC, amitriptyline should be effectively removed.

An approach to minimizing the impact of PPCPs on the source water would be for Santa Fe to work with upstream communities to try to minimize the discharge of pharmaceuticals to the Rio Grande with wastewater effluent. One way to do this would be to encourage medication collection programs that discourage people from flushing unused medications down the toilet.

Operational Procedures to Limit Flow of Contaminated Water into the C/CWTP

The above contaminant-by-contaminant analysis indicates that the C/CWTP should be able to provide water meeting all SDWA maximum contaminant levels on a continuous basis for all contaminants discussed in this report. Concentrations in the source water are nearly always below the regulated levels, and the proposed treatment plant includes processes that have been demonstrated to be effective for most of the contaminants. Despite this, it would provide an additional level of protection to provide as much source-water protection as possible, and limit the flow of water into the C/CWTP when concentrations in the river are suspected to be higher. As discussed earlier in this report, source water protection can be improved by (1) encouraging LANL to provide measures to minimize the transport of contaminants from LANL property to the Rio Grande and (2) encouraging upstream communities to develop pharmaceutical collection programs that would reduce the discharge of pharmaceuticals to the river. It has been demonstrated that contaminant concentrations in the river are highest during storm events. The impact of storm events on the river water quality is relatively easy to monitor with turbidity, a continuous on-line measurement. The design documents for the C/CWTP describe a strategy to cease diversions when the TSS in the river exceeds 3000 mg/L. While the intended purpose for this operational strategy is to reduce the potential for solids deposition in pipelines and basins (which have a significant impact on operating and maintenance costs), the strategy has the added benefit of additional protection of finished water quality. The inclusion of this strategy into the operation of the C/CWTP further decreases the likelihood that additional treatment would ever be needed for cesium, radium strontium, or perchlorate in the future.

Ion Exchange

Ion exchange has been identified as a possible process to provide additional treatment should it become necessary. Ion exchange is a fixed bed process in which the water is passed through a column containing a resin. The resin contains exchangeable ions of the same charge as the ions to be removed from the water. As water passes through the column, the target ions transfer to the resin surface and the exchangeable ions transfer to the water to maintain the charge balance in both phases.

Ion exchange resins are available in both cation and anion forms, and the proper resin must be used for the ion to be removed from water. As noted earlier in the chemistry section, cesium, radium, and strontium are present in solution in cationic form, and could be removed from water with a cation exchange resin. Perchlorate and chromium(VI) can be effectively removed from water with an anion exchange resin. Ion exchange would not be necessary to remove uranium, plutonium, and americium from water since they are effectively removed by the coagulation/ filtration process, but uranium and plutonium would be primarily removed by anion exchange resins whereas a cation exchange resin would probably be necessary for americium. Tritium and PCBs would not be effectively removed with ion exchange.

An important issue with ion exchange is the regeneration of the resin and disposal of the waste stream. The resin is regenerated using a strong brine solution that strips the target ions from the resin and replaces the sites with the original exchangeable ions. The brine solution must then be discarded. If toxic or hazardous chemicals were removed from the source water, they will be concentrated in the brine solution. Waste disposal can be one of the problematic and expensive aspects of ion exchange.

An advantage of ion exchange is that the resin columns could be by-passed when the treatment capability was not needed. Since the contaminants discussed in this report almost never appear in the source water, a column could be on standby instead of in active use, which would minimize the regeneration and brine disposal problems. The addition of standby columns, however, would be a significant capital expense and would be unlikely to provide a health benefit to the public.

Reverse Osmosis

Reverse osmosis (RO) is a membrane-based physicochemical treatment process used to separate dissolved solutes from water. The membrane is a semipermeable material that allows water molecules to pass through, but rejects solutes at the membrane surface. RO is considered best available technology for a wide array of contaminants, including alpha and beta activity, radium, uranium, and chromium. RO would also be expected to be effective for removal of plutonium, americium, cesium, strontium, and perchlorate, and reasonably effective for PCBs and many PPCPs. RO would not be effective for removing tritium from water.

While RO is one of the most robust and effective treatment processes available, it has a number of disadvantages that should be considered before implementation, including:

1. RO is sensitive to feed water quality and cannot accommodate feed water with appreciable quantities of solids in it. RO would not be able to treat Rio Grande water without an effective upstream filtration process. In other words, RO could not be used as a replacement for the membrane filtration process that is currently included in the proposed C/CWTP process train, but would be an additional process added to the end of the train. However, the RO process could probably replace the ozone/GAC process, since the RO process would remove the contaminants that are the target of that process.
2. RO operates at relatively low recovery compared to other treatment processes. In inland systems, the treated water produced is typically 70 to 85 percent of the feed water. For instance, a 15 mgd plant operating at 75 percent recovery would need 20 mgd of feed water to produce 15 mgd of treated water and a 5 mgd waste stream. Thus, the capacity of the entire proposed treatment plant would have to be increased to accommodate the low recovery of the RO process.
3. In addition to having to increase the size of the C/CWTP, a significant portion of the water diverted from the Rio Grande would become a waste stream. In an arid area where drought and water availability are important issues, the large waste stream inherent in the RO process is a waste of precious resources.
4. Disposal of the waste stream is often one of the biggest problems in implementing RO facilities. The RO process concentrates all solutes from the feed water into a smaller waste stream, including all constituents that contribute to salinity. In coastal areas, the

waste stream is typically discharged to the ocean. In inland areas, surface water discharge is typically impractical because the salinity of the waste stream is above acceptable limits for surface water discharge. The typical options are evaporation ponds or deep well injection of the wastes. Few industrial deep well permits exist in New Mexico, and it may not be possible to locate a suitable injection zone near Santa Fe. Evaporation ponds for a 5 mgd waste stream represent an enormous investment because the ponds must be lined to prevent groundwater contamination. In the case of Rio Grande water, it is conceivable, however, that Santa Fe may be able to obtain a NPDES permit to discharge the waste back to the Rio Grande, since the total dissolved solids of the river is relatively low at the diversion point, and an increase in concentration by 4 to 5 times may still be within acceptable limits. In addition, it is unlikely that the waste would contain any hazardous constituents that would limit discharge to the river. Permitting a waste discharge to the Rio Grande, however, would be a long and expensive process, and may not be fruitful in the end.

5. RO is an extremely energy intensive process, operating at 100 to 200 psi even for ultra-low pressure installations (and up to 1200 psi for seawater installations). The electrical energy required for the operation of the RO pumps contribute to a sizeable carbon footprint, and it is possible that the RO process would cause more environmental damage through the production of greenhouse gases than the benefits that would be realized by the higher level of treatment being provided.
6. RO removes virtually all solutes, including essential minerals and nutrients. Recently, evidence has been mounting that RO-treated water is less healthy to drink because of the removal of calcium and magnesium [47].

Both ion exchange and reverse osmosis would represent a significant additional capital cost to the C/CWTP. Based on the information presented in this report, it does not appear that the addition of these technologies would result in a health benefit to the consumers of the water from the C/CWTP. In addition, both technologies have negative environmental consequences such as energy consumption and waste production that must be considered before implementation. Therefore, the addition of either of these processes into the proposed process train cannot be recommended at this time.

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